Course Title: **Radiological Control Technician**
Module Title: **Interaction of Radiation with Matter**
Module Number: **1.07**

Objectives:

1.07.01 Identify the definitions of the following terms:
- a. ionization
- b. excitation
- c. bremsstrahlung

1.07.02 Identify the definitions of the following terms:
- a. specific ionization
- b. linear energy transfer (LET)
- c. stopping power
- d. range
- e. W-value

1.07.03 Identify the two major mechanisms of energy transfer for alpha particulate radiation.

1.07.04 Identify the three major mechanisms of energy transfer for beta particulate radiation.

1.07.05 Identify the three major mechanisms by which gamma photon radiation interacts with matter.

1.07.06 Identify the four main categories of neutrons as they are classified by kinetic energy for interaction in tissue.

1.07.07 Identify three possible results of neutron capture for slow neutrons.

1.07.08 Identify elastic and inelastic scattering interactions for fast neutrons.

1.07.09 Identify the characteristics of materials best suited to shield:
- a. alpha
- b. beta
- c. gamma
- d. neutron radiations

References:

1. "Basic Radiation Protection Technology"; Gollnick, Daniel; Pacific Radiation Press; 1994.
2. ANL-88-26 (1988) "Operational Health Physics Training"; Moe, Harold; Argonne National Laboratory, Chicago.

3. "Radiological Health Handbook"; Bureau of Radiological Health; U. S. Department of Health, Education, and Welfare; Washington, D.C.; 1970.
4. "The Health Physics and Radiological Health Handbook"; Edited by Bernard Shleien; Scint, inc., Silver Spring, MD.; 1992.

Instructional Aids:

1. Overheads
2. Overhead projector/screen
3. Chalkboard/whiteboard
4. Lessons learned

I. MODULE INTRODUCTION

A. Self-Introduction

1. Name
2. Phone number
3. Background
4. Emergency procedure review

B. Motivation

The understanding of how radiation interacts with matter is fundamental when providing radiological protection. You as an RCT should be particularly interested in how radiation is absorbed by the body for three reasons.

1. Absorption in body tissues may result in physiological injury
2. Absorption is the principle upon which detection is based.
3. The degree of absorption and type of interaction is a primary factor in determining shielding requirements

C. Overview of Lesson

1. Definitions of terminology used in the lesson
2. Mechanisms of Energy transfer for each type of ionizing radiation
3. Shielding characteristics
4. Interactions of radiation with our bodies

D. Introduce Objectives

O.H.: Objectives

II. MODULE OUTLINE

A. Transfer of Energy Mechanisms (absorption) for radiations include:

Objective 1.07.01

1. Ionization

See Fig. 1 - "Ionization"

   a. Any process which results in the removal of an electron (with negative one charge) from an electrically neutral atom or molecule

   b. Whenever this happens it creates an ion pair made up of the negative electron and the positive atom or molecule. Some examples of the energy required to produce one ion pair:

   He = 42.7 eV
   Ar = 26.4 eV
   N_2 = 36.5 eV
   Air = 33.9 eV

2. Excitation

See Fig. 2 - "Excitation"

   a. Transfer of energy to (absorption by) the electrons or nucleus of an atom or molecule. This energy is less than that required for ionization. The process raises an electron from one energy level to a higher energy level within the atom and the atom remains electrically neutral.

   b. It is also important to remember that all of the particles or ray produced by primary interactions lose their energy the same way, ionization and excitation, in secondary interactions.

3. Bremsstrahlung

   a. Bremsstrahlung is the radiative energy loss of moving charged particles as they interact with the matter through which they are moving.

   b. Bremsstrahlung radiation results from the interaction of a high speed particle near a heavy (high Z) atom. The particle is deflected from its course by the electrostatic force of the positively charged nucleus. The kinetic energy the electron loses is emitted as X-ray radiation.

The photon emitted is an X-ray because it originated outside the nucleus.

B. Direct Ionizing Radiation

1. Charged particles do not require contact to interact because the "Coulomb force" (force from the charge) will act over a distance to cause ionization and excitation in the absorber medium. This force is dependent on:

    a. energy (speed) of particle

    b. charge of particle

    c. density and number of absorber

2. Interaction concepts

    Objective 1.07.02
    See Table 1 - "Summary of Energy Loss Terms and Units"

    a. Specific Ionization (S.I.)

        1) Number of ion pairs formed by a charged particle per unit path length (ion pairs/cm). This is dependent on the material type of ionizing particle and the material being ionized.

    b. Linear Energy Transfer (LET)

        1) Average energy locally deposited in an absorber by a charged particle per unit distance of travel (keV/cm)

        2) Is useful for calculating quality factors

    c. Stopping Power (S)

        1) Average energy lost by a charged particle per unit distance of travel (keV/cm)

    d. Range (R)

        1) Average depth of penetration of a charged particle into an absorber before it loses all of its kinetic energy and stops (cm)

        2) Inversely related to stopping power

        high range = low stopping power
        low range = high stopping power

e. W-value (W)	
1) Average amount of energy needed to produce an ion pair in a given medium	
2) Allows one to relate Specific Ionization to Range or Stopping Power	(W)(S.I.) = S or (eV/ion pair)(ion pairs/cm) = eV/cm
3. Alpha Absorption	See Fig. 3 - "Ionization by an Alpha Particle"
a. Large charge +2	
b. Large mass 4 AMU's	
c. Interactions	Objective 1.07.03
1) Ionization	
2) Excitation	
d. Interaction concepts	
1) Spec. ionization - very high	
2) LET ------------ very high	
3) Stopping power - very high	
4) Range----------- very low	
4. Beta particles	
a. Charge -1	
b. Mass 5.49 E-04 AMU	
c. Interactions	Objective 1.07.04
1) Ionization	
2) Excitation	
3) Bremsstrahlung	See Fig. 4 - "Bremsstrahlung Radiation"

d. Interaction concepts

1) Specific ionization - high

2) LET------------------- high

3) Stopping power----- high

4) Range------------- low

C. Indirect Ionizing Radiation

1. Indirect ionizing radiations, having no charge, do not readily interact with matter.

2. When they do, they may produce direct ionizing radiation particles (charged particles) which will produce many secondary ions

3. Probability of interaction is dependent on

a. Density and Z number of the absorber

b. Energy of the radiation

4. Photon Interactions

Objective 1.07.05

a. Photoelectric Effect

See Fig. 5 - "Photoelectric Effect"

1) The photon transfers all of its energy to an electron; ejecting the electron from the atom

2) The photon disappears

3) Almost always a "K" shell electron (inner shell - lowest energy level)

4) Generally low energy gamma (eV range)

b. Compton Scattering

See Fig. 6 - "Compton Scattering"

1) Photon transfers a part of its energy to an electron (binding energy + kinetic energy = beta particle + lesser energy photon)

2) The less energetic photon (Compton photon) has its direction of travel changed and may undergo further Compton scatter or photoelectric effect interactions in the absorber

3) Any electrons except "K" shell (outer shells - higher energy levels)

4) Generally occurs with middle energy gamma (low MeV range)

5) Optional Note:

The mechanism of Compton Scattering was first fully explained in 1923 by physicist A. H. Compton. He correctly suggested that the photons could be thought of as carrying a bundle of energy like a billiard ball, and that the resulting angles and energies of the electron and residual photon could be computed using the classical laws of physics i.e. conservation of energy and momentum. This explanation was initially rejected by others because it was felt that photons and other forms of electromagnetic energy were really waves which could not exhibit particle-like properties. Compton received the Nobel Prize in physics in 1927 for this discovery.

c. Pair Production

See Fig. 7 - "Pair Production and Annihilation"

1) In an interaction between the electromagnetic field of a high Z number nucleus and a photon - all of the energy of the photon is transformed into an electron and a positron (two charged particles) each having some kinetic energy.

2) Very high energy gamma required because a minimum energy is required (1.022 MeV to make the mass of the two particles) in fact, it may take energy levels greater than 2 or 3 MeV and then only a very small part of all interactions will cause pair production

3) What happens to the two particles?

   a) Ionization, excitation, and bremsstrahlung occurs for both particles. When the positron loses almost all of its energy, it will then be attracted to an electron and will annihilate releasing two photons of equal energy (511 keV each).

4) This process demonstrates Einstein's mass-energy relationship $E = mc^2$ works in both directions

d. Photon interaction review

1) photoelectric effect: low energy = eV range

2) compton scattering: med energy = Low MeV

3) pair production: very high energy = High MeV

4. Neutron Interactions

a. Classified by:

1) Kinetic energy of the neutron

Objective 1.07.06
See Table 2 - "Neutron Energy Categories"

   a) Thermal: ($\leq$0.5 eV)

   b) Intermediate: (0.5 eV - 100 keV)

   c) Fast: (100 keV - 20 MeV)

   d) Relativistic: (> 20 MeV)

2) Z number of target

   a) Lower Z numbers absorb more energy per each interaction or collision

3) Absorption cross section of target

   a) Some elements absorb neutrons more readily than others i.e. cadmium, boron, and hafnium

b. Slow Neutron Interactions (Capture) — Objective 1.07.07

1) Radiative Capture: neutron is absorbed into nucleus and a gamma is emitted. This is also called gamma emission or neutron activation.

2) Charged Particle Emission: neutron is absorbed into nucleus and a charged particle is emitted

3) Fission: neutron is absorbed into nucleus then the nucleus splits into fission fragments.

c. Fast Neutron Interactions (Scatter) — Objective 1.07.08

1) Elastic Scattering: kinetic energy is the only form of energy involved. — See Fig. 8 - "Elastic Scattering"

2) Inelastic Scattering: some kinetic energy is changed to excitation energy of the nucleus which then emits a photon (gamma ray) to remove this excitation energy. — See Fig. 9 - "Inelastic Scattering"

d. Remember neutrons are not charged particles but neutron interactions do produce charged particles and photons, which will cause large amounts of secondary ionization and excitation

D. Shielding

1. Equations

a. $I = I_o e^{-ux}$

b. $I = I_o$ (½^n = thickness divided by the Half Value Layer (HVL)

2. Cautions

a. In thick shielding you have to account for buildup factor which is due to the scattering of radiation in the absorber

b. "Sky Shine" is radiation reflected back to earth by the atmosphere.

c. Scattering can cause radiation to go around corners or edges of shielding

d. High beta dose rate shielded with high Z absorber may increase dose rate due to bremsstrahlung production

3. Typical shielding materials

Objective 1.07.09
See Table 3 - "Shielding Material"

a. alpha paper

b. beta low Z (rubber, aluminum, plastic)

c. gamma (lead, steel)

d. neutron low Z (Hydrogenous Materials)

1) The use of materials with a high Hydrogen concentration will moderate (slow down) the neutron intensity.

2) Lower energy neutrons are easily captured by materials with a high cross section for absorption. (Boron, Cadmium)

3) When shielding for neutron radiation consideration must be given for gamma production from activation of shielding material and bremsstrahlung X rays.

III. SUMMARY

A. Review major topics

1. Definitions of terminology used in the lesson.

2. Mechanisms of Energy transfer for each type of ionizing radiation.

3. Shielding characteristics

4. Interactions of radiation with our bodies.

B. Review learning objectives

IV. EVALUATION

Evaluation should consist of a written examination comprised of multiple choice questions. 80% should be the minimum passing criteria for the examination.

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